THE DESIGN AND MEASUREMENT OF A
MICROWAVE MODE TRANSDUCER

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BY

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Lieutenant, United States Navy

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the requirements for the degree of

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ABSTRACT

A MODE TRANSDUCER TO SEPARATE THE TE_{10} AND TE_{20} MODES PROPAGATING IN MULTIMODE WAVEGUIDE AND COUPLE THE POWER FROM EACH INTO SINGLE MODE WAVEGUIDES IS DESCRIBED. THE CONSTRUCTION OF AN EXPERIMENTAL MODEL IS SHOWN AND DATA ON ITS PERFORMANCE GIVEN. THE CAPABILITIES OF THIS TYPE OF MODE TRANSDUCER ARE DISCUSSED AND MODIFICATIONS TO GIVE IMPROVED PERFORMANCE ARE SUGGESTED.

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LIST OF ILLUSTRATIONS

1. Introduction

Investigation of the scattering by a slot in a multimode waveguide required the development of a specialized microwave bridge[1] for taking experimental data. The requirement for a better mode transducer for use in this bridge initiated the project described in this paper.

When two or more modes may propagate in the same waveguide, it is not easy to determine by measurement the amplitude and phase of each. The difficulties are mainly practical ones, which would not arise if the experimenter had at his disposal infinitesimal probes that could be moved about within the guide at will without disturbing the existing fields.

The slotted-line technique is not applicable for it is impossible to cut a slot in the multimode guide that will be everywhere parallel to the lines of current flow in each of the two modes and will therefore seriously disturb the field of neither.

The method of measuring the fields in the multimode waveguide that was adopted consisted of first transforming the power in the TE_{20} mode from the multimode waveguide to TE_{10} in single mode guide and similarly transforming the TE_{10} power in the multimode guide to TE_{10} in another single mode guide. The phase and amplitude of the fields

[1] Capt. Ralph L. Lary, USMC, A Microwave Bridge for the Accurate Measurement of Scattering Matrices Generated by Obstacles in Multimode Waveguide, U.S.N.P.S. Thesis, 1862

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PROPAGATING IN THE SINGLE MODE WAVEGUIDES CAN NOW BE
MEASURED AND SERVE TO INDICATE THE FIELDS EXISTING IN THE
MULTIMODE WAVEGUIDE. THE DEVICE USED TO AFFECT THIS
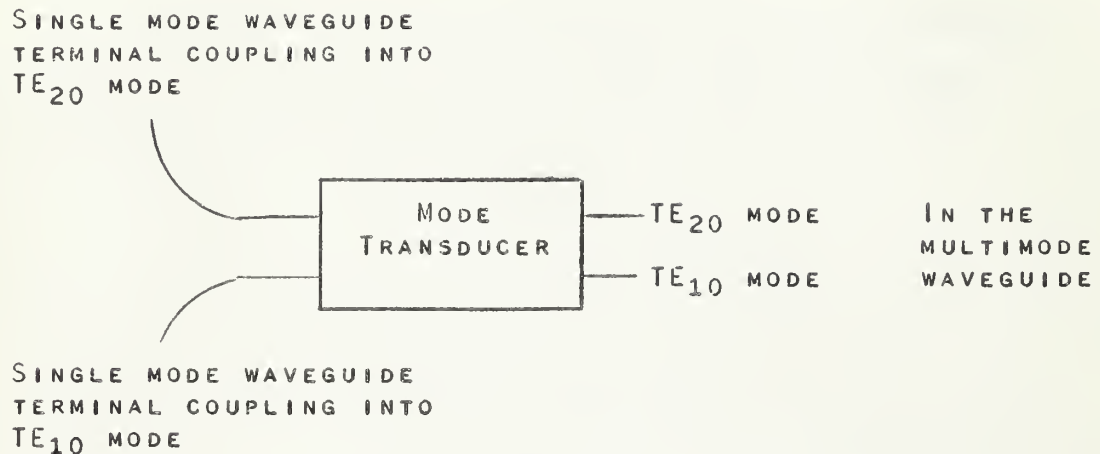TRANSORMATION IS A MODE TRANSDUCER.

SINGLE MODE WAVEGUIDE
TERMINAL COUPLING INTO
TE_{20} MODE

| MODE TRANSDUCER | — TE_{20} MODE | IN THE MULTIMODE |
| — TE_{10} MODE | WAVEGUIDE |

SINGLE MODE WAVEGUIDE
TERMINAL COUPLING INTO
TE_{10} MODE

FIGURE 1

AN IDEAL MODE TRANSDUCER WILL BE DEFINED TO HAVE THE
FOLLOWING PROPERTIES:

A. IT SHOULD PRESENT A PERFECT MATCH TO POWER ENTER-
ING EITHER OF THE SINGLE MODE PORTS WHEN THE MULTIMODE
PORT IS TERMINATED IN A MULTIMODE MATCHED LOAD (MATCHED
FOR BOTH MODES). ALSO THERE SHOULD BE NO REFLECTION OF
EITHER THE TE_{10} OR THE TE_{20} ENERGY ENTERING THE MULTIMODE
PORT WHEN THE SINGLE MODE PORTS ARE TERMINATED IN MATCHED
LOADS.

B. THERE SHOULD BE NO COUPLING BETWEEN MODES. TE_{10}
ENTERING THE MULTIMODE PORT SHOULD NOT BE REFLECTED AS
TE_{20} OUT OF THE MULTIMODE PORT OR TRANSMITTED THROUGH THE
TE_{20} SINGLE MODE PORT. TE_{20} ENTERING THE MULTIMODE PORT

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SHOULD NOT BE REFLECTED AS TE_{10} OUT OF THE MULTIMODE PORT
OR TRANSMITTED THROUGH THE TE_{10} SINGLE MODE PORT. SIMILARLY
ENERGY ENTERING EITHER OF THE SINGLE MODE PORTS SHOULD BE
CONVERTED ENTIRELY TO THE DESIRED MODE IN THE MULTIMODE
WAVEGUIDE.

THE PERFORMANCE OF A MICROWAVE MODE TRANSDUCER CAN BE
SPECIFIED BY THE DEGREE TO WHICH THESE TWO PARAMETERS,
MATCH AND ISOLATION, ARE OBTAINED.

2. Representation of a Mode Transducer by the Scattering Matrix

A mode transducer can be viewed as a junction of four waveguides. Two of the junctions are the single mode waveguide ports and the other two ports represent the two propagating modes possible in the multimode waveguide. Figure 2 depicts the mode transducer as a junction of four waveguides with only one mode propagating in each arm.

FIGURE 2

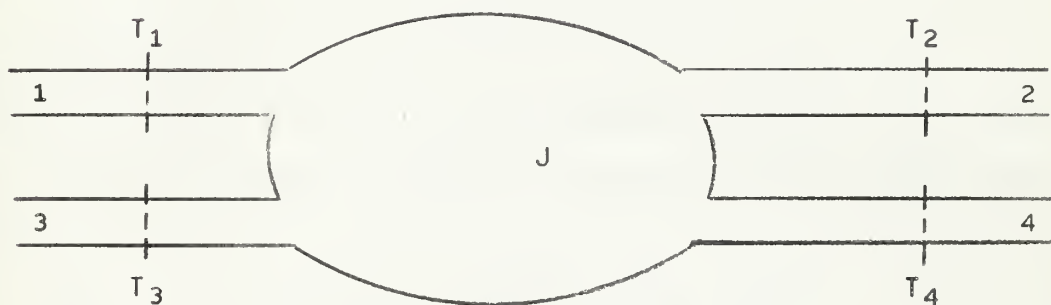Terminal number one represents the single mode waveguide port that couples into the TE_{20} mode in the multimode waveguide.

Terminal number two represents the TE_{20} mode in the multimode guide.

Terminal number three represents the single mode waveguide port that couples into the TE_{10} mode in the multimode guide.

Terminal number four represents the TE_{10} mode in the multimode guide.

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A COMPLETE DESCRIPTION OF THE FIELDS WITHIN THE DIS-
CONTINUITY REGION OF THE JUNCTION, J, WOULD REQUIRE, IN
ADDITION TO THE DOMINANT PROPAGATING MODES, AN INFINITY
OF NON-PROPAGATING MODES. THIS COMPLICATION IN THE FIELD
DESCRIPTION THAT EXISTS AT THE JUNCTION CAN BE AVOIDED BY
LOOKING ONLY AT THE DOMINANT MODES AT TERMINAL PLANES T_1
THROUGH T_4 LOCATED SUFFICIENTLY DISTANT FROM THE JUNCTION
SO THAT THE NON-PROPAGATING HIGHER-ORDER MODES HAVE VANISH-
ED. IN THE SCATTERING TYPE OF REPRESENTATION THE FIELDS
ARE DESCRIBED BY THE AMPLITUDES OF THE INCIDENT AND
REFLECTED WAVES AT EACH OF THE TERMINAL PLANES. FOR A TE
MODE THE FIELDS AT THE TERMINAL PLANE T_J ($Z=Z_J$) ARE GIVEN
BY:/1/

$$\vec{E}_J(x,y,z_J) = A_J \vec{\mathcal{E}}_J^{+} + B_J \vec{\mathcal{E}}_J^{-}$$

$$\vec{H}_J(x,y,z_J) = A_J \vec{\mathcal{H}}_J^{+} + B_J \vec{\mathcal{H}}_J^{-}$$

WHERE $\vec{\mathcal{E}}_J$ AND $\vec{\mathcal{H}}_J$ ARE VECTOR MODE FUNCTIONS CHARACTERISTIC
OF THE TRANSVERSE FORM OF THE DESIRED MODE IN THE J^{TH} GUIDE.

FOR TE_{MN} MODES IN RECTANGULAR GUIDE:/2/

$$\vec{\mathcal{E}} = \left(E_x \vec{I}_x + E_y \vec{I}_y \right) e^{j\omega t}$$

$$\vec{\mathcal{H}} = \left(H_x \vec{I}_x + H_y \vec{I}_y + H_z \vec{I}_z \right) e^{j\omega t}$$

WHERE:

$$E_x = \frac{j\omega N K_y}{K_x^2 + K_y^2} \cos K_x X \ \sin K_y Y$$

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$$E_y = -\frac{j\omega N K_x}{K_x^2 + K_y^2} \, SIN \, K_x X \, COS \, K_y Y$$

$$H_x = \frac{\gamma_{mm} K_x}{K_x^2 + K_y^2} \, SIN \, K_x X \, COS \, K_y Y$$

$$H_y = \frac{\gamma_{mm} K_y}{K_x^2 + K_y^2} \, COS \, K_x X \, SIN \, K_y Y$$

$$H_z = COS \, K_x X \, COS \, K_y Y$$

$$\gamma_{mm} = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{m\pi}{b}\right)^2 - \omega^2 N\epsilon}$$

$$K_x = \frac{m\pi}{a} \qquad\qquad K_y = \frac{m\pi}{b}$$

THE PLUS AND MINUS SUPERSCRIPT INDICATE PLUS AND MINUS

TRAVELING WAVES. A_J AND B_J ARE, RESPECTIVELY, THE COMPLEX

AMPLITUDES OF THE ELECTRIC FIELD IN THE INCIDENT AND

REFLECTED WAVE COMPONENTS OF THE DESIRED MODE FIELD AT

TERMINAL T_J. SINCE $\vec{\mathcal{E}}_{m,m}$ AND $\vec{\mathcal{H}}_{m,m}$ ARE BASIS VECTORS, ANY

SOLUTION TO THE FIELD EQUATIONS IN RECTANGULAR GUIDE MAY

BE REPRESENTED BY SUITABLE FOURIER METHODS.

THE FUNDAMENTAL EXISTENCE THEOREM /1/ APPLICABLE TO

THE SCATTERING FORMULATION OF A FIELD PROBLEM STATES THAT

THE AMPLITUDES OF THE SCATTERED WAVES AT THE VARIOUS

TERMINALS ARE UNIQUELY RELATED TO THE AMPLITUDES OF THE

INCIDENT WAVES THEREON. IN THE CASE OF LINEAR OBSTACLES,

THE AMPLITUDES OF THE REFLECTED WAVES SET UP AT THE TERMINAL

PLANES T_1, . . . T_J BY A SINGLE INCIDENT WAVE A_1 AT T_1, OR A_2 AT T_2, . . ., ETC., ARE:

$$B_1 = S_{11}A_1 \qquad B_1 = S_{12}A_2 \qquad B_1 = S_{1J}A_J$$
$$B_2 = S_{21}A_1 \qquad B_2 = S_{22}A_2 \qquad B_2 = S_{2J}A_J$$
$$\cdot \qquad\qquad \cdot \qquad\qquad \cdot$$
$$\cdot \qquad\qquad \cdot \qquad\qquad \cdot$$
$$B_J = S_{J1}A_1 \qquad B_J = S_{J2}A_2 \qquad B_J = S_{JJ}A_J$$

BY SUPERPOSITION THE AMPLITUDES OF THE SCATTERED WAVES RESULTING FROM THE SIMULTANEOUS INCIDENCE OF WAVES OF AMPLITUDES A_1, . . . A_J ARE:

$$B_1 = S_{11}A_1 + S_{12}A_2 \; . \; . \; + S_{1J}A_J$$
$$B_2 = S_{21}A_1 + S_{22}A_2 \; . \; . \; + S_{2J}A_J$$
$$\cdot$$
$$\cdot$$
$$B_J = S_{J1}A_1 + S_{J2}A_2 \; . \; . \; + S_{JJ}A_J$$

WHERE THE SCATTERING COEFFICIENT S_{JK} IS A MEASURE OF THE AMPLITUDE AND PHASE OF THE WAVE SCATTERED INTO THE J^{TH} GUIDE BY A WAVE OF UNIT AMPLITUDE INCIDENT INTO THE K^{TH} GUIDE. NOTE THEREFORE THAT S_{JJ} REPRESENTS THE REFLECTION COEFFICIENT AT THE TERMINAL T_J WHEN ALL OTHER TERMINALS ARE MATCHED. IN MATRIX FORM THE SCATTERING PROPERTIES OF A WAVEGUIDE STRUCTURE ARE EXPRESSED BY THE ARRAY OF COEFFICIENTS CALLED THE SCATTERING MATRIX.

$$S = \begin{pmatrix} S_{11} & S_{12} \cdots S_{1N} \\ S_{21} & \\ \cdot & \\ \cdot & \\ S_{N1} & \quad\quad\quad S_{NN} \end{pmatrix}$$

IT CAN BE SHOWN /1/ THAT THE SCATTERING MATRIX IS SYMMET-
RICAL AND FOR NON-DISSIPATIVE STRUCTURES IT IS UNITARY.
THIS MEANS THAT:

$$S_{JK} = S_{KJ}$$

AND

$$\sum_{\alpha=1}^{N} S_{\alpha m}^{*} S_{\alpha m} = \delta_{mm} = \begin{cases} 1 & \text{IF } m = m \\ 0 & \text{IF } m \neq m \end{cases}$$

FOR A FOUR TERMINAL JUNCTION IT HAS BEEN SHOWN BY
W. H. KUMMER /3/ THAT THE FOLLOWING RELATIONS HOLD:

$S_{13} = S_{14} = S_{23} = S_{24}$, $S_{12} = 1 - S_{11}$, $S_{11} = S_{22}$.

APPLYING THESE RELATIONSHIPS AND THE RECIPROCITY RELATIONS
TO THE SCATTERING MATRIX FOR A FOUR TERMINAL MODE TRANS-
DUCER IT CAN BE SEEN THAT ONLY THREE SCATTERING COEFFICIENTS
ARE REQUIRED TO COMPLETELY SPECIFY THE SCATTERING MATRIX.

$\longrightarrow$ $S_{11} = S_{22}$

$\longrightarrow$ $S_{33} = S_{44}$

$\longrightarrow$ $S_{13} = S_{31} = S_{14} = S_{41} = S_{23} = S_{32} = S_{24} = S_{42}$

$\quad\quad S_{12} = 1 - S_{11} = S_{21}$

$\quad\quad S_{34} = 1 - S_{33} = S_{43}$

The scattering coefficients of an ideal mode transducer would be:

$$S_{12} = S_{21} = S_{34} = S_{43} = 1$$

$$S_{11} = S_{13} = S_{14} = 0$$

$$S_{22} = S_{23} = S_{24} = 0$$

$$S_{31} = S_{32} = S_{33} = 0$$

$$S_{41} = S_{42} = S_{44} = 0$$

The scattering matrix of an ideal mode transducer would be:

$$S = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

3. Design of the Mode Transducer

The transition from the TE_{10} mode in the multimode guide to the TE_{10} mode single mode guide is a relatively simple matter. Since the field configuration is the same in both guides the problem is almost equivalent to that of providing a reflectionless junction between two transmission lines of different characteristic impedance. A quarter wave matching section is a common method of providing a reflectionless junction but it has the disadvantage of being frequency sensitive. In order to allow operation over a broad band of frequencies the impedance transformation was made by means of an intermediate section in which a gradual change from the dimensions of one guide to those of the other takes place (see Figure 3). Provided this tapered section is at least a few wavelengths long there will be very little reflection over a wide frequency band. Since the dimensions of the single mode guide are such that the TE_{20} mode cannot propagate freely, any TE_{20} energy incident will see a reactive termination and will be attenuated rapidly in the single mode guide.

Single Mode Guide   Multimode Guide

Figure 3

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THE TRANSITION FROM TE$_{20}$ IN MULTIMODE GUIDE TO TE$_{10}$

IN SINGLE MODE GUIDE CAN BE ACCOMPLISHED IN VARIOUS WAYS /2/.

THE METHOD USED WAS CHOSEN BECAUSE "MODE PURITY", THAT IS,

THE FREEDOM OF EXCITATION OF THE UNDESIRED TE$_{10}$ MODE,

DEPENDS ON PHYSICAL SYMMETRY ONLY, AND IS, IDEALLY, NOT A

FUNCTION OF FREQUENCY. FIGURE 4 SHOWS HOW THIS WAS

ACCOMPLISHED. THE SEPTUM AT A DIVIDES THE FIELDS MIDWAY

ACROSS THE MULTIMODE GUIDE AND THEY PROPAGATE AS TE$_{10}$ IN

ARMS B AND C. AS SHOWN BY THE E FIELD VECTORS, TE$_{20}$

INCIDENT UPON THE JUNCTION BECOMES TE$_{10}$ WITH IDENTICAL

AMPLITUDES IN EACH ARM BUT 180° OUT OF PHASE. THE 90°

TWISTS, CLOCKWISE IN ONE ARM AND COUNTERCLOCKWISE IN THE

OTHER, GIVE A NET 180° ROTATION BETWEEN THE TWO ARMS BRING-

ING THE E FIELDS BACK IN PHASE AT JUNCTION D WHERE THEY ADD

AND EMERGE AT E AS A TE$_{10}$ FIELD IN SINGLE MODE WAVEGUIDE.

MOST OF THE TE$_{10}$ INCIDENT AT THE MULTIMODE PORT IS SHORTED

BY THE SEPTUM AT A BUT THE REMAINDER BECOMES TE$_{10}$ BUT WITH

THE SAME PHASE IN EACH ARM. AFTER BEING ROTATED AT B AND C

THE NET RESULT IS A 180° PHASE DIFFERENCE BETWEEN THE

FIELDS AND COMPLETE CANCELLATION AT THE JUNCTION D. IF

THE CROSS SECTION OF THE GUIDE IS CHANGED SLOWLY AND

UNIFORMLY OVER A DISTANCE OF SEVERAL WAVE LENGTHS THE

TE$_{20}$ INCIDENT AT THE MULTIMODE PORT WILL BE TRANSFORMED

INTO TE$_{10}$ IN THE SINGLE MODE GUIDE WITH LITTLE REFLECTION.

THE DEGREE OF MODE PURITY THAT CAN BE OBTAINED DEPENDS

UPON HOW CLOSELY THE ELECTRICAL LENGTHS OF THE TWO ARMS

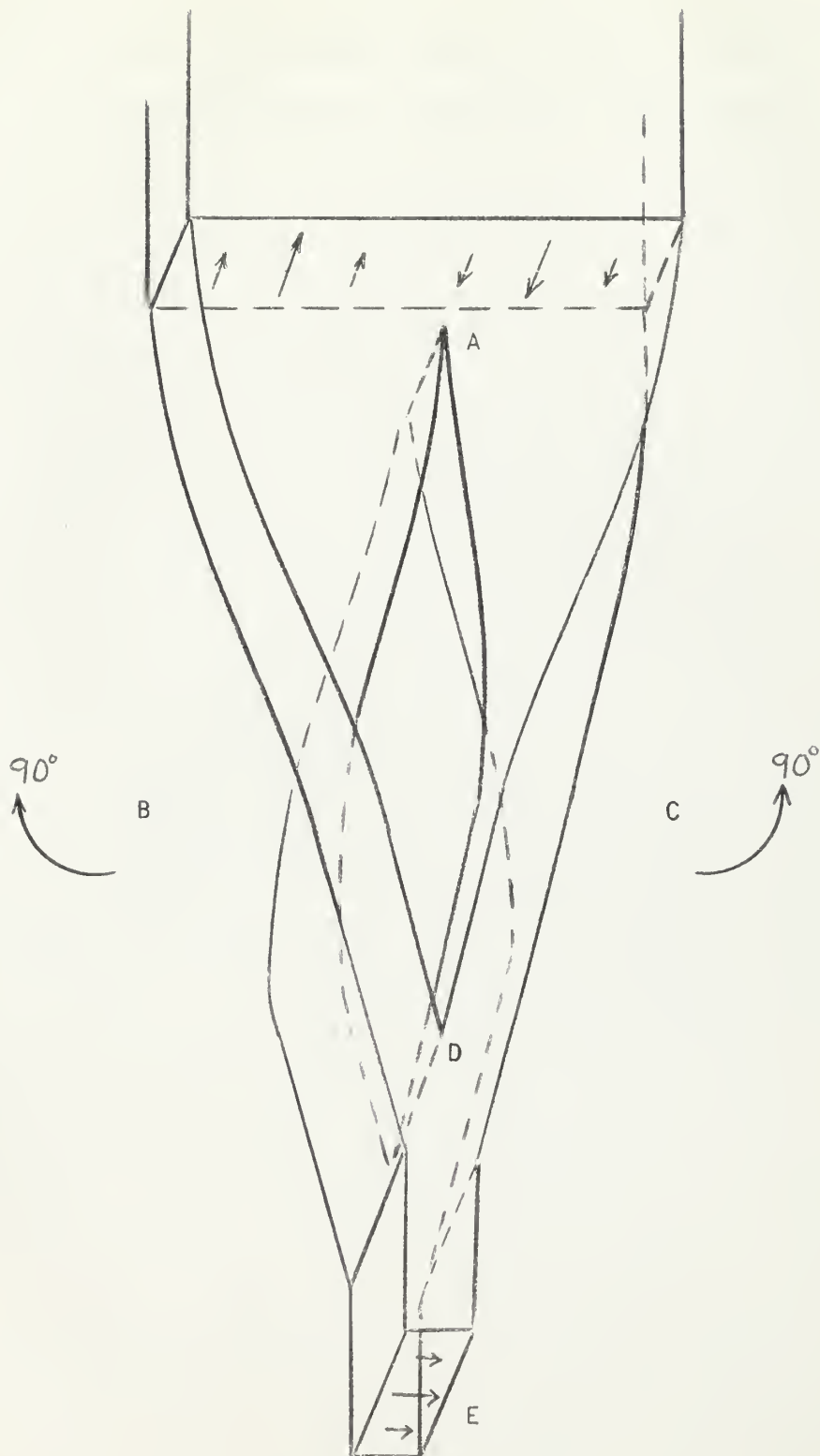CAN BE MATCHED AND HOW ACCURATELY THE FIELDS SPLIT AT

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FIGURE 4

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JUNCTION D. IF THIS TRANSDUCER COULD BE CONSTRUCTED WITH
MIRROR SYMMETRY ABOUT THE CENTER LINE COMPLETE ISOLATION
BETWEEN THE TE_{10} AND TE_{20} MODES WOULD BE OBTAINED AND,
FURTHER, THIS ISOLATION WOULD BE FREQUENCY INDEPENDENT.

4. Construction of the Mode Transducer

The design principles just described were applied to the construction of a transducer for separating the TE_{20} and TE_{10} in multimode guide and transforming them to single mode guide. Since both of the methods used to transform the fields required access to the full width of the multimode guide, another septum was introduced splitting the narrow dimension of the guide, and consequently dividing the E field equally above and below the septum (Figure 5).
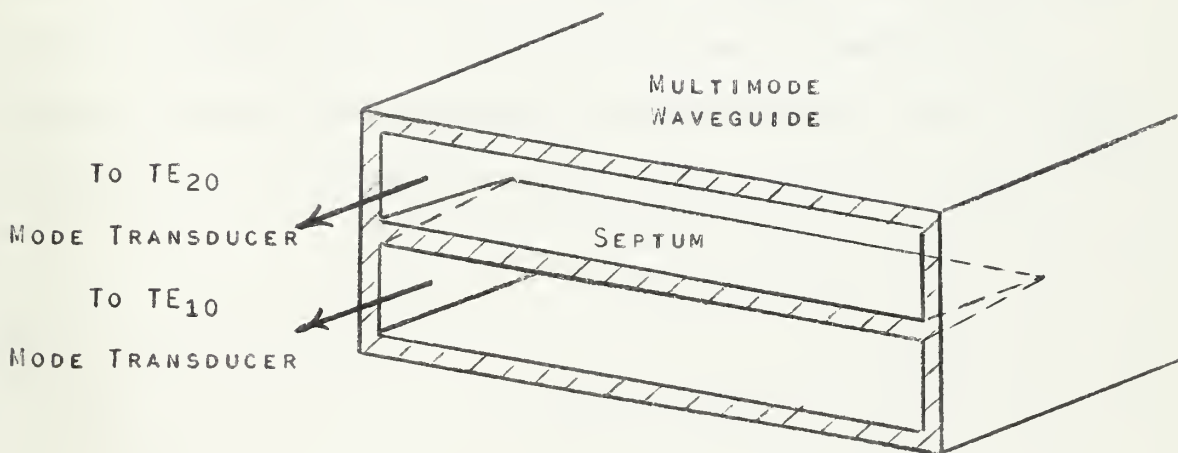
Multimode
Waveguide

To TE_{20}
Mode Transducer

Septum

To TE_{10}
Mode Transducer

Figure 5

The lower section of the guide tapered uniformly into a cross section of single mode dimensions thereby forming the TE_{10} port. The upper section of the multimode guide was

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BIFURCATED AND THE CROSS SECTIONS OF EACH ARM TAPERED TO CONFORM TO THE DIMENSIONS OF X BAND SINGLE MODE GUIDE. AT THESE POINTS TWO PIECES OF WAVEGUIDE, WITH OPPOSITE 90° TWISTS, WERE ATTACHED. AFTER THE TWISTS THE GUIDES CAME TOGETHER AGAIN IN A TAPERED E PLANE Y JUNCTION THAT ENDED IN A STANDARD X BAND WAVEGUIDE FLANGE FORMING THE TE_{20} PORT. AT THE E PLANE Y JUNCTION A BENDABLE SEPTUM EXTENDING INTO THE COMMON ARM WAS PROVIDED TO ALLOW FOR ADJUSTING THE DIVISION OF THE E FIELD AT THAT POINT. DETAILS OF THE CONSTRUCTION CAN BE SEEN IN FIGURES 6, 7, AND 8. THE THREE PIECES IN FIGURE 6 WERE MILLED OUT OF BRASS STOCK. THE TWISTS IN FIGURE 7 WERE FABRICATED FROM STANDARD RG58 X BAND WAVEGUIDE AND THE Y JUNCTION WAS MADE BY SANDWICHING TOGETHER TWO BEVELED SECTIONS OF WAVE-GUIDE AND A SHEET BRASS SEPTUM.
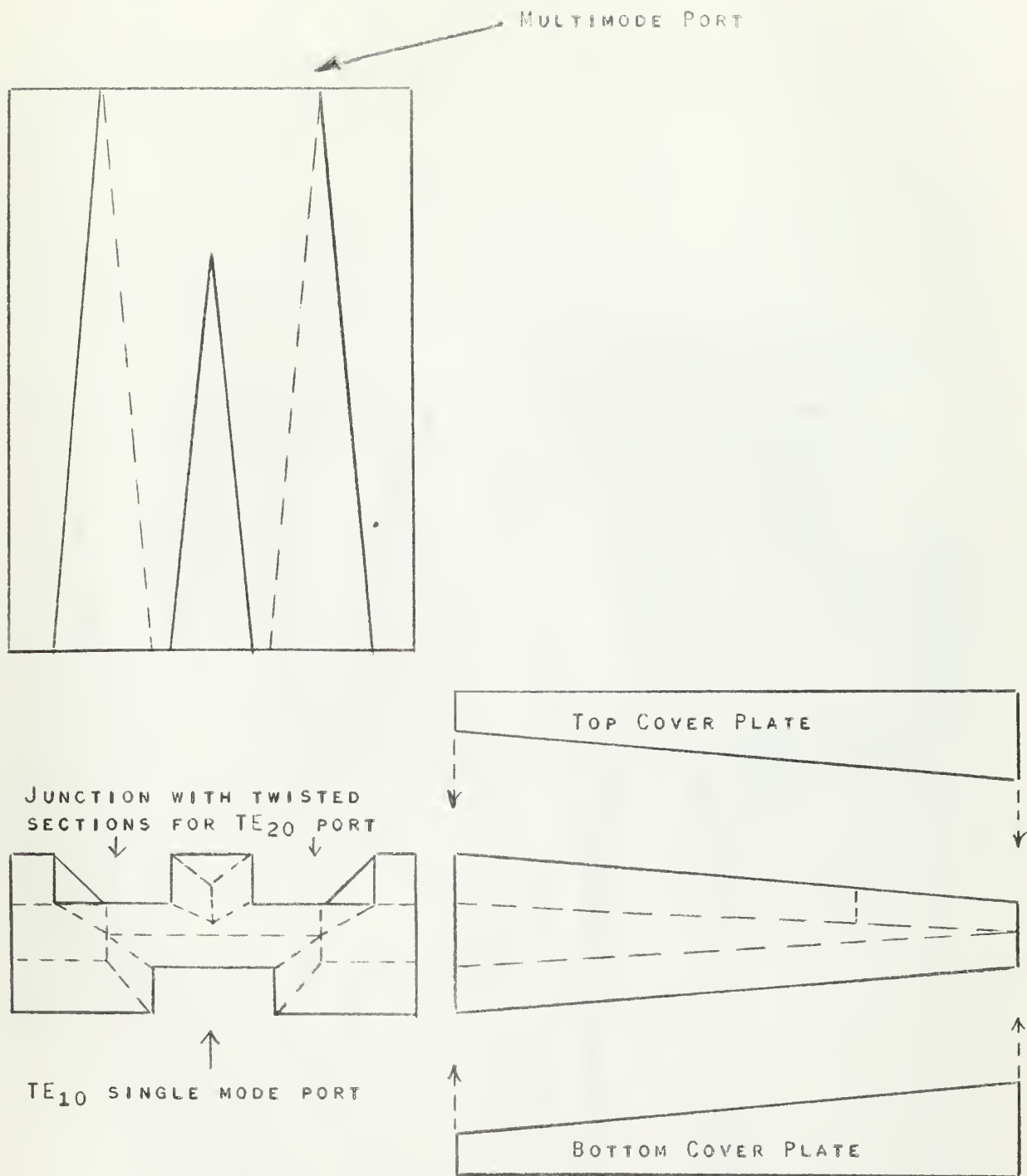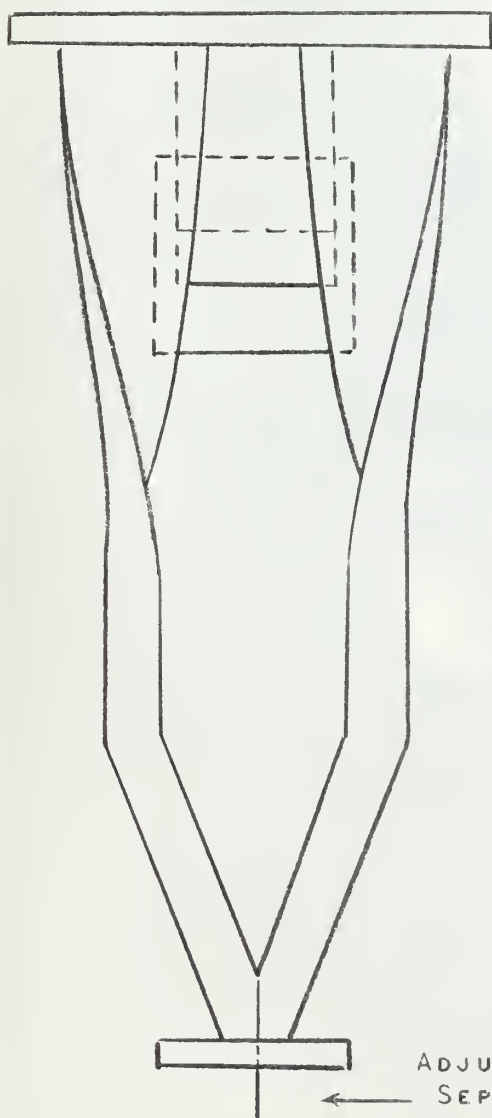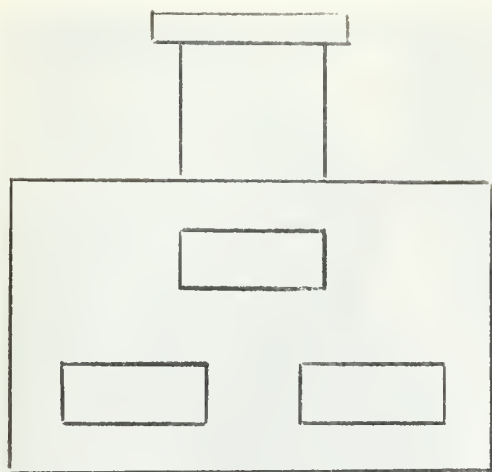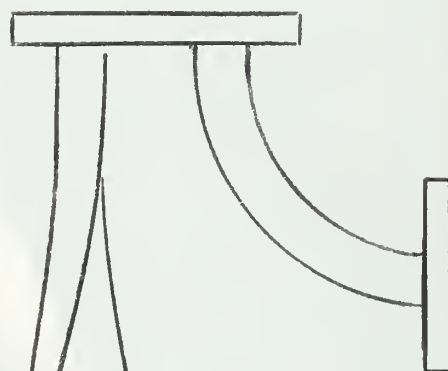
MULTIMODE PORT

JUNCTION WITH TWISTED
SECTIONS FOR TE$_{20}$ PORT

TOP COVER PLATE

TE$_{10}$ SINGLE MODE PORT

BOTTOM COVER PLATE

FIGURE 6

FLANGE BOLTS TO BRASS
BLOCK IN FIGURE 6.

TE$_{10}$ SINGLE
MODE WAVEGUIDE
PORT

TE$_{20}$ SINGLE
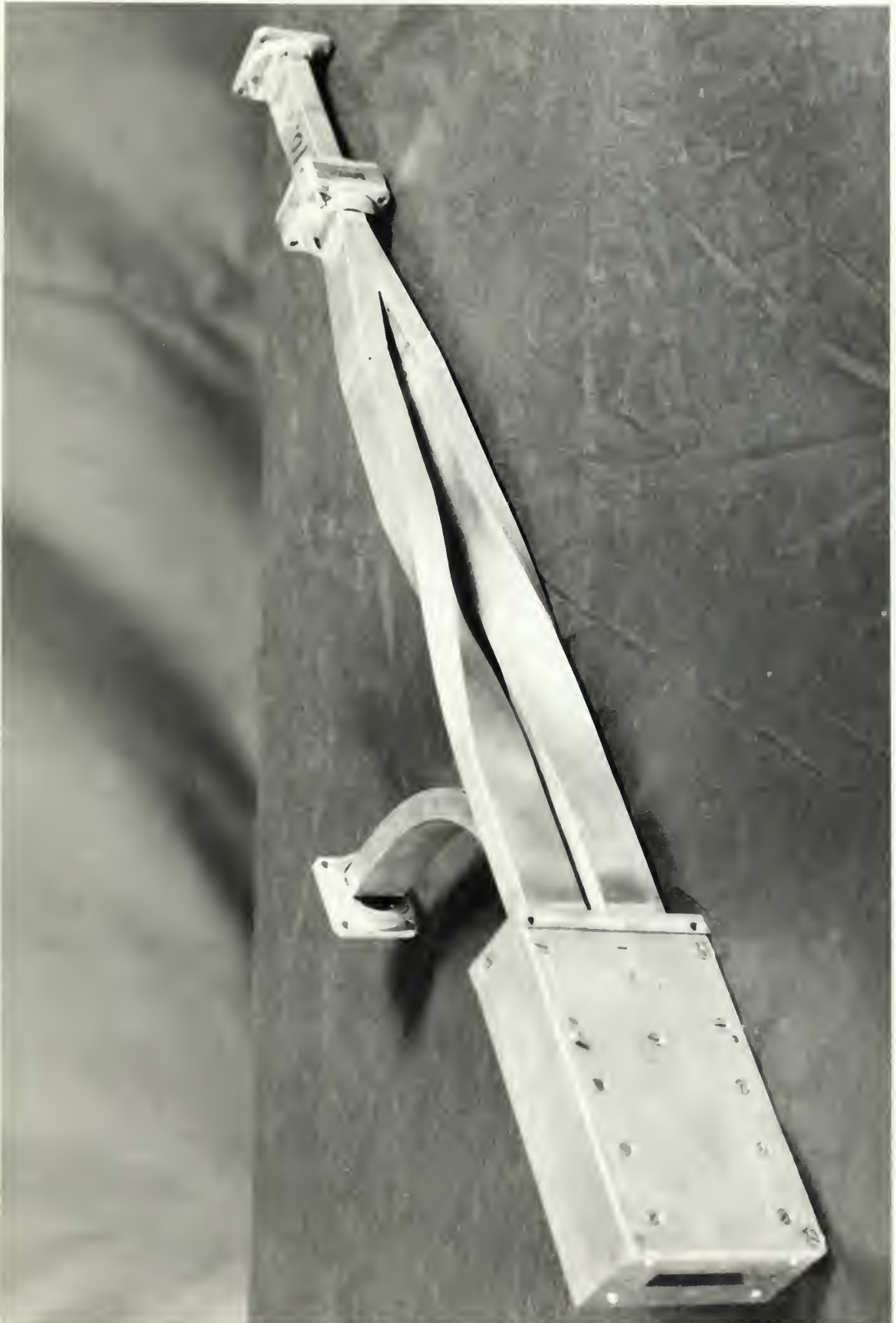MODE WAVEGUIDE
PORT

ADJUSTABLE
SEPTUM

FIGURE 7

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FIGURE 8

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5. Measuring the Characteristics of the Mode Transducer

A ratio bridge was adapted, as shown in Figure 9, to measure the S.R at the TE_{20} and TE_{10} single mode ports and also to measure the isolation between them. This data could then be used to find the amplitudes of the scattering coefficients. (Details of the measurement bridge are covered in Footnote 1.) With approximately two watts available from the klystron amplifier the maximum sensitivity allowed measuring power ratios up to 70 db.

When the isolation between modes was first measured it was found to be on the order of 20 db. This was considerably worse than the existing mode transducers that were in use and which had an isolation of about 45 db. Adjustment of the septum at the Y junction improved isolation somewhat but the main cause of the cross-coupling between modes was the difference in electrical lengths of the twisted waveguide sections. In order to determine the potential mode separation possible with this type of mode transducer without requiring the machine shop to build an _identically_ symmetrical device, one of the twisted sections was tuned to the same electrical length as the other by squeezing the broad faces of the waveguide together slightly. This adjustment in conjunction with the septum adjustment reduced the cross-coupling between modes to an immeasurable amount. Although excellent isolation was obtained at the frequency at which the adjustments were made (9.375 KMC) the band-

WIDTH WAS REDUCED BECAUSE THE PHASE VS. FREQUENCY
CHARACTERISTICS OF THE TWISTED SECTIONS WERE NOW QUITE
DIFFERENT.

THE REFLECTED POWER AT THE TE_{10} AND TE_{20} SINGLE MODE
PORTS CORRESPONDING TO $\left| S_{33} \right|$ AND $\left| S_{11} \right|$ ARE SHOWN IN DB IN
FIGURE 10. THE COUPLING BETWEEN THE TE_{10} AND TE_{20} SINGLE
MODE PORTS CORRESPONDING TO $\left| S_{13} \right|$ IS SHOWN IN FIGURE 11.
FIGURES 12 AND 13 SHOW THE SWR AND ISOLATION FOR THE MODE
TRANSDUCER PREVIOUSLY EMPLOYED. THE MULTIMODE PORT WAS
TERMINATED WITH A MULTIMODE MATCHED LOAD FOR ALL MEASURE-
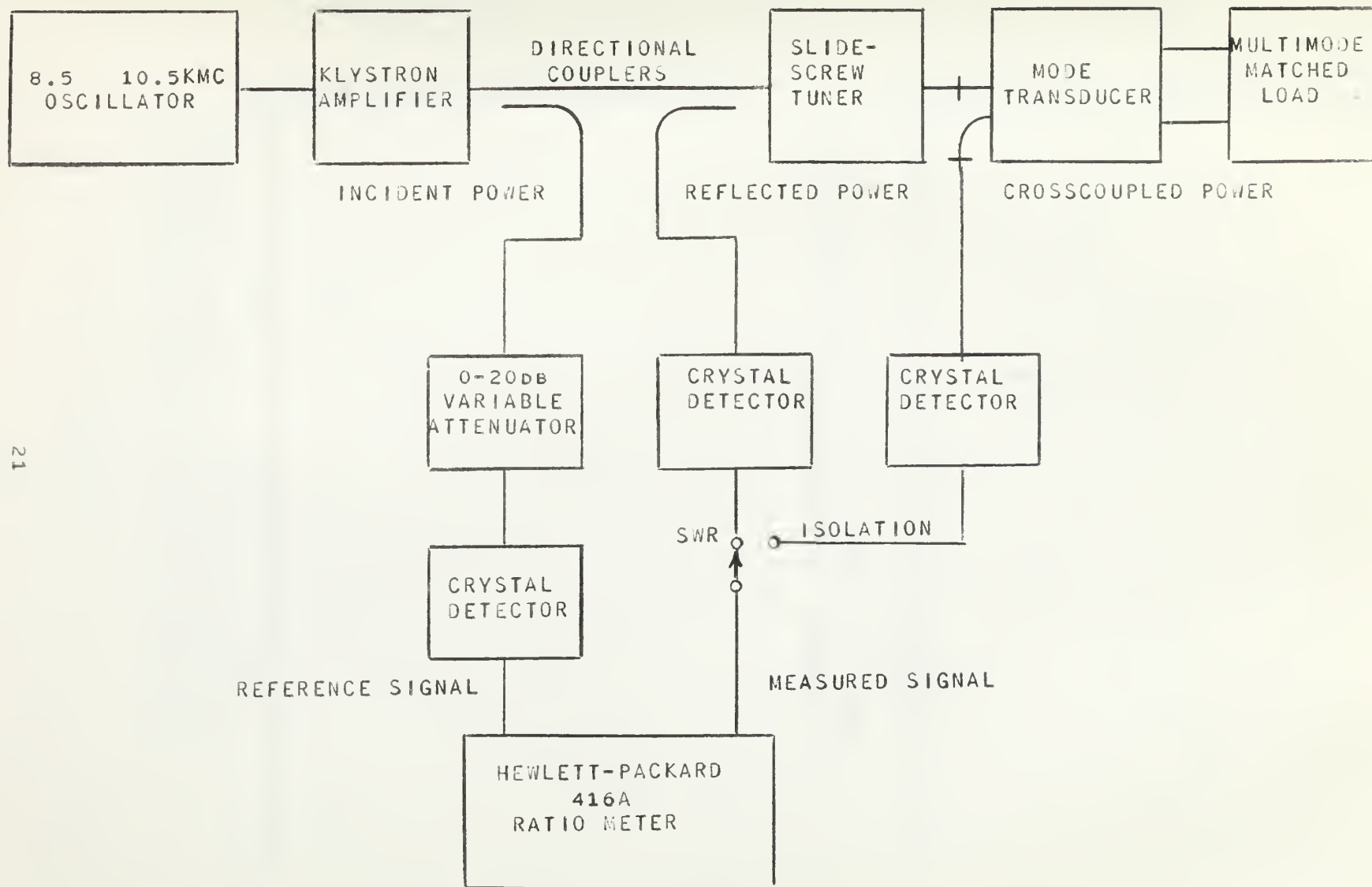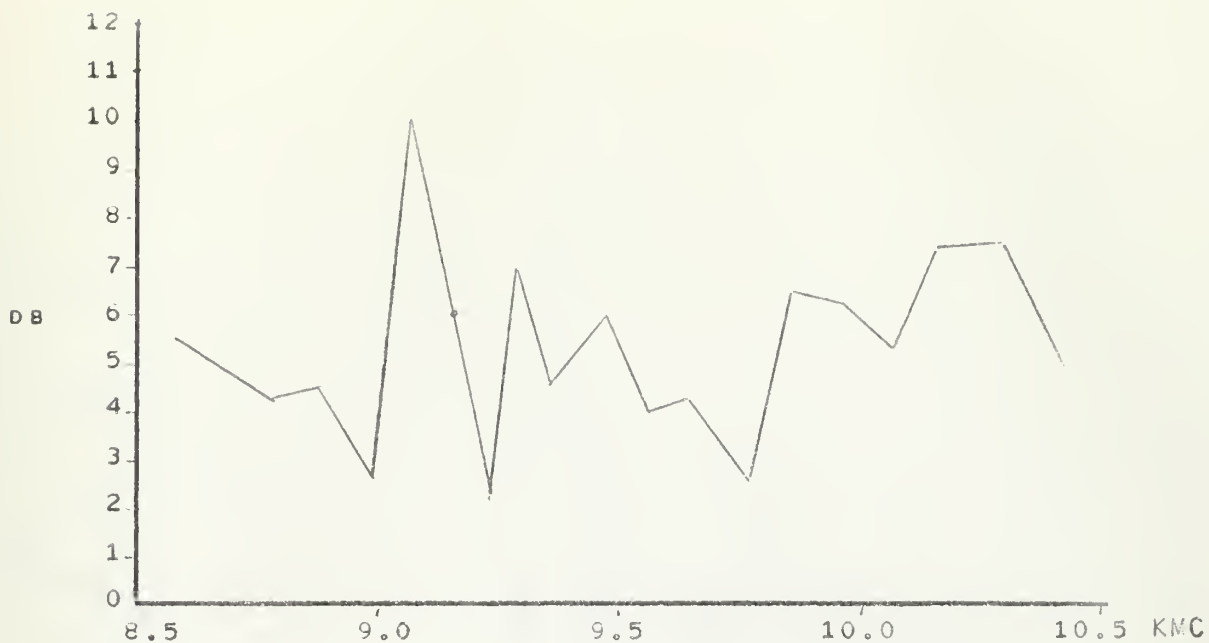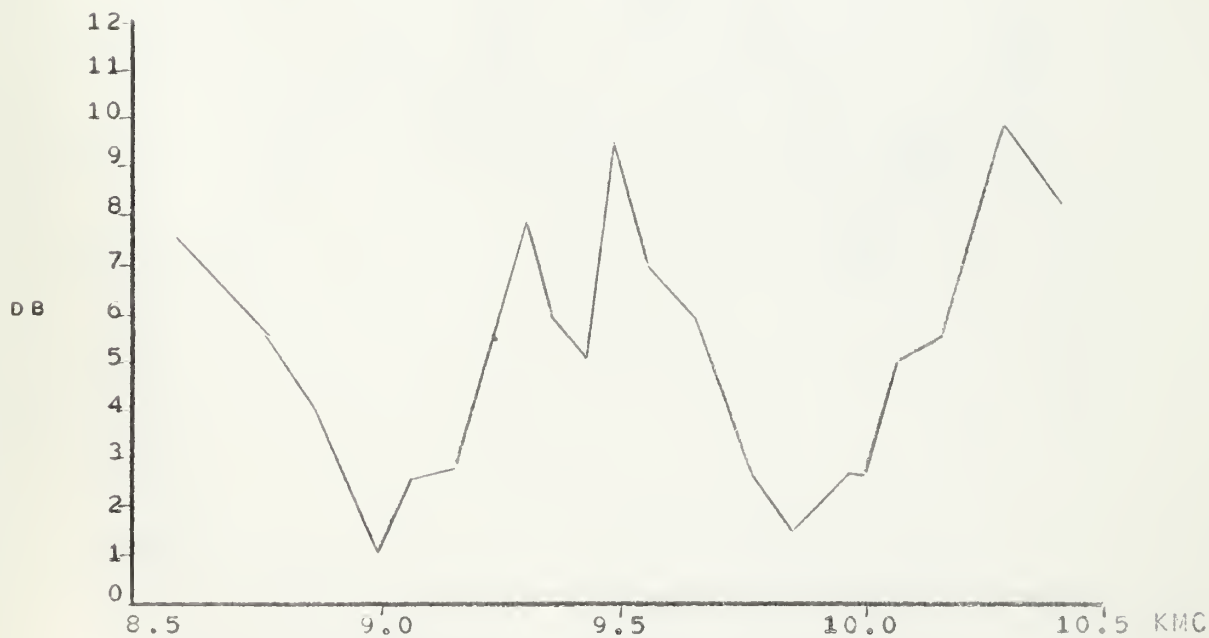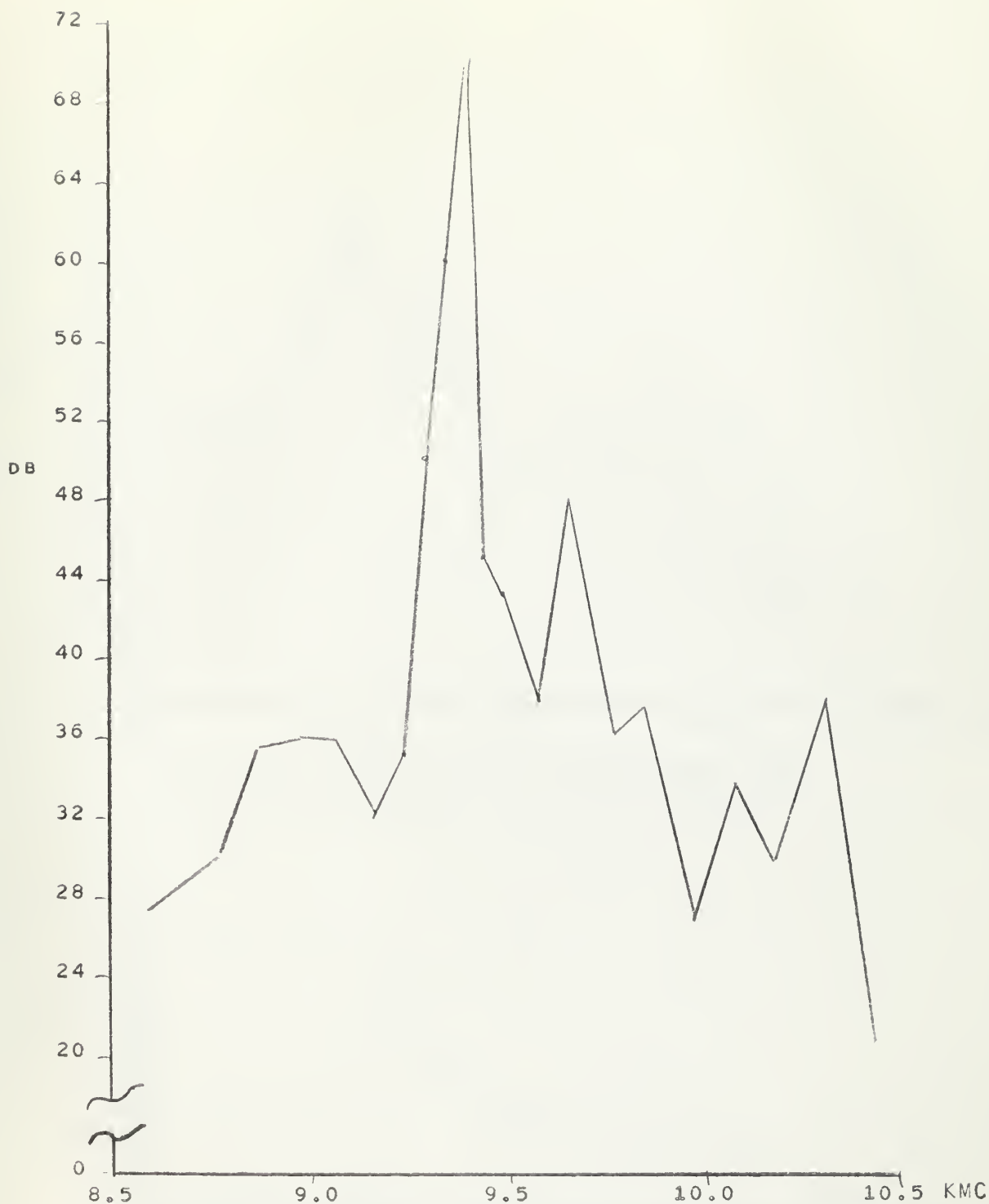MENTS.

FIGURE 9

REFLECTED POWER AT TE_{10} SINGLE MODE PORT
IN DB BELOW INCIDENT POWER VS. FREQUENCY

REFLECTED POWER AT TE_{20} SINGLE MODE PORT
IN DB BELOW INCIDENT POWER VS. FREQUENCY

FIGURE 10

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ISOLATION BETWEEN TE_{10} AND TE_{20} SINGLE
MODE WAVEGUIDE PORTS VS. FREQUENCY

FIGURE 11
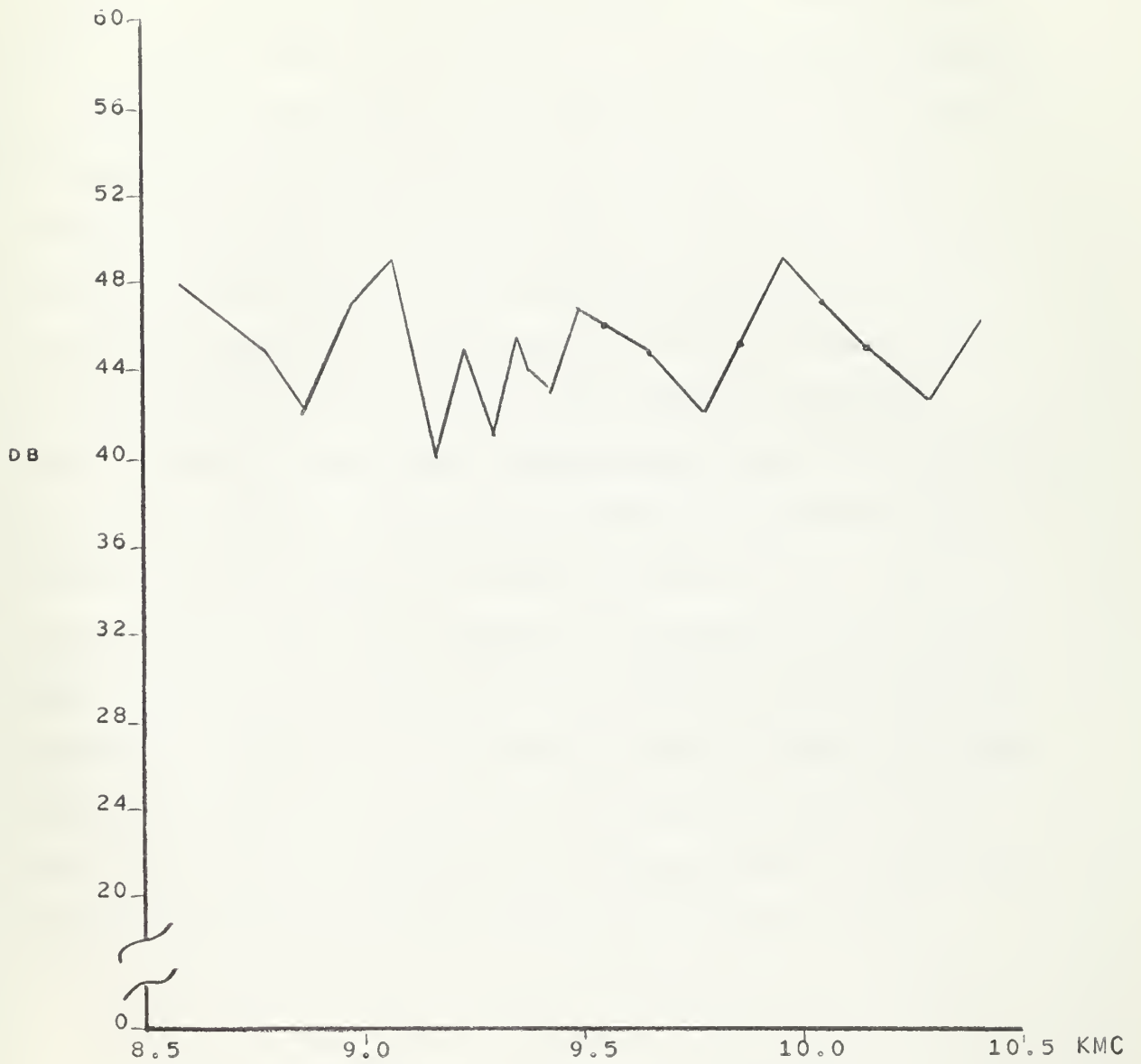
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NOTE CHANGE OF SCALE

REFLECTED POWER AT TE_{10} SINGLE MODE PORT
IN DB BELOW INCIDENT POWER VS. FREQUENCY

REFLECTED POWER AT TE_{20} SINGLE MODE PORT
IN DB BELOW INCIDENT POWER VS. FREQUENCY.

FIGURE 12

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ISOLATION BETWEEN TE_{10} AND TE_{20} SINGLE
MODE WAVEGUIDE PORTS VS. FREQUENCY

FIGURE 13

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6. Recommended Modifications to Improve Performance

The primary cause of the high SWR is the reactive load seen by (A) the TE_{20} mode incident upon the portion of the transducer designed to couple out the TE_{10}, and (B) the TE_{10} incident upon the portion of the transducer designed to couple out the TE_{20}. This problem can be reduced by extending the septum dividing the multimode guide and introducing a resistive E field vane in the center of the section through which the TE_{20} mode should propagate and similarly introduce a resistive slot in the center of the section through which the TE_{10} mode should propagate. These resistive loads would selectively absorb the rejected mode in each arm of the mode transducer eliminating the reactive terminations as a cause of reflection. These modifications would also improve the isolation since the undesired mode would be largely attenuated before reaching the region in which it is normally cancelled out. Although this would mean a 3 db loss in coupling out each of the modes, it would not create any problems when used with the multimode microwave bridge referenced in Footnote 1.

7. Conclusions

While the performance of the mode transducer was adequate for use at a single frequency in the multimode measurement bridge, the full realization of the bandwidth capabilities inherent in this design will require adherence to extremely close manufacturing tolerances. For example, at 9.375 KMC five thousandths of an inch in the X band guide corresponds to one degree of phase shift. The difference in phase shift between the two halves of the mode transducer should be held to a fraction of a degree.

Although the reflection coefficients were small enough so that slide screw tuners could be used to achieve a match, a marked improvement in the SWR should result from the modifications described in Section 6.
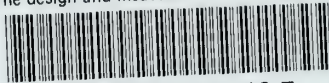
This method of mode conversion is capable of attaining excellent isolation and a low SWR over a broad frequency range providing that the strigent requirements on physical symmetry can be met.

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